Integrated Mineral-Resource and Mineral-Environmental Assessments of Public Lands: Applications for Land Management and Resource Planning

U. S. Geological Survey
Geologic Division
Office of Mineral Resources

Orange, iron-rich sediments precipitated by mine-drainage waters—Rawley Tunnel, Bonanza, Colorado

By

**Geoffrey S. Plumlee,
Steven M. Smith,
Margo I. Toth,
and Sherman P. Marsh**

With contributions from:

S. D. Ludington, A. R. Wallace,
W. H. Ficklin, K. S. Smith,
J. T. Nash, N. K. Foley,
R. E. Van Loenen, B. R. Berger,
and G. Green

**U. S. Geological Survey
Open-File Report 93-571**

This report is preliminary and has not been reviewed for conformity with U. S. Geological Survey editorial standards.

Mineral-deposit geology is an important control on natural contamination from unmined mineral deposits, and on the environmental effects of mining and mineral processing.

The U. S. Geological Survey, Office of Mineral Resources (USGS/OMR) is now integrating geology-based environmental assessments into its mineral resource assessments of public and other lands.

This report presents prototype mineral-environmental assessments of the State of Colorado and the San Juan National Forest. The following pages will show examples of how geologic information can be used to help predict and prevent adverse environmental effects of mineral-resource development.

Overview

I. Background

A. Some environmental effects of mineral deposits and mineral-resource development.
B. Environmental-geology models of mineral deposits; their uses in predicting mine-drainage chemistry.

II. Mineral-Resource and Mineral-Environmental Assessment of Colorado

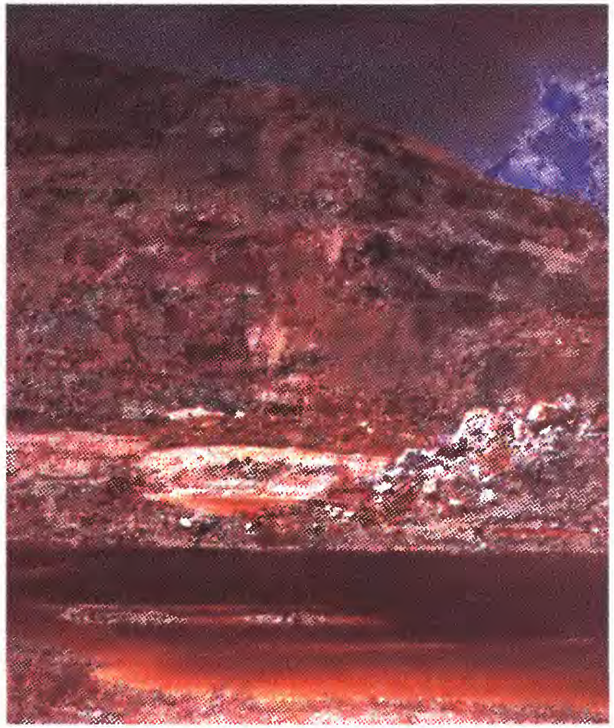
A. Streams affected by metals.
B. Regional environmental studies; lead concentrations in stream sediments of Colorado.
C. "Summitville-Type" deposits: their environmental characteristics and occurrences in Colorado.
D. "Leadville-Type" deposits: their environmental characteristics and occurrences in Colorado.
E. Applications of regional geoscience surveys and environmental-geology models of mineral deposits to land management and resource planning.

III. Mineral-Resource and Mineral-Environmental Assessment of the San Juan National Forest

A. Location of mining districts and streams affected by metals.
B. Mineral-resource assessment map.
C. Environmental geology map.
D. Sources of acidity in streams.
E. Geology-based environmental risk assessment.
F. Applications of integrated mineral-resource and mineral-environmental assessments to land management and resource planning.

U.S. Department of the Interior
U.S. Geological Survey

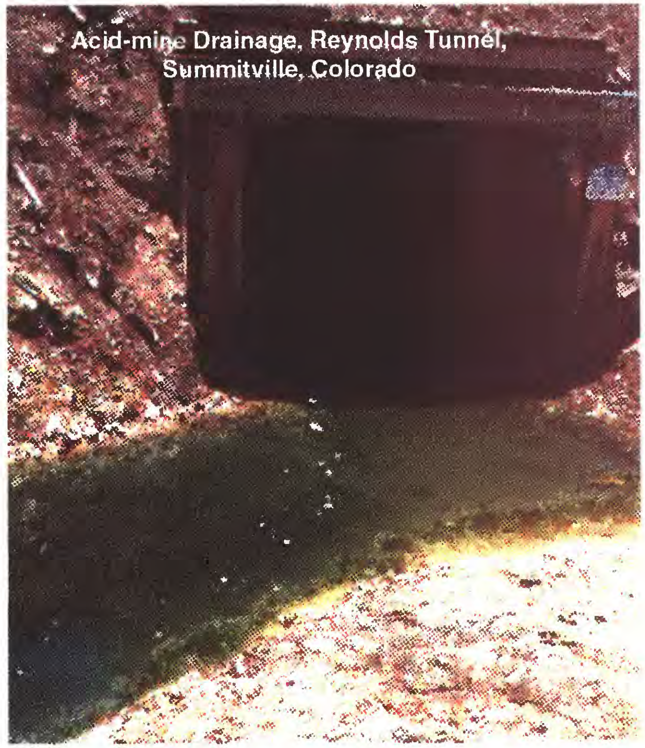
Center for Environmental Geochemistry and Geophysics
CEGG



Acid waters, Summitville Open Pit, Colorado

Integrated Mineral-Resource and Mineral-Environmental Assessments of Public Lands: Applications for Land Management and Resource Planning

I. Background

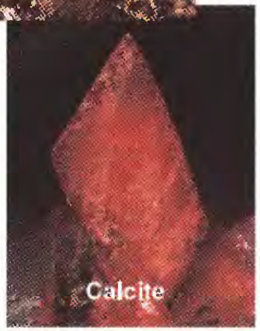


Some Environmental Effects of Mineral Deposits and Mineral-Resource Development

The Cause

Most mineral deposits contain sulfide minerals such as pyrite (an iron-sulfide). When oxygen-rich waters react with sulfide minerals, they often acquire high concentrations of acid and of potentially toxic elements such as zinc, copper, cadmium, and arsenic.

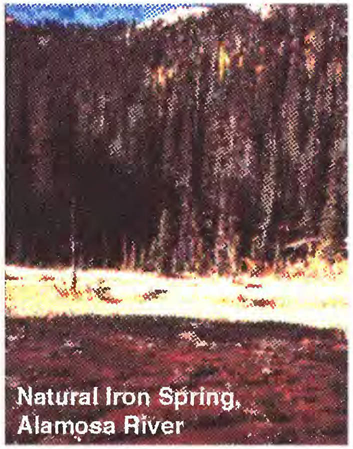
Pyrite



Calcite

Carbonate minerals such as calcite consume acid and can help reduce the acidity and concentrations of some metals (such as arsenic and copper) in mine waters. However, waters draining sulfide- and carbonate-rich mineral deposits often are not acidic but still carry high concentrations of some metals such as zinc.

Acid Rock Drainage



Natural Iron Spring, Alamosa River

Sulfide-rich rocks are common in nature. Acidic and metal-bearing waters that drain from these rocks can be a significant source of natural pollution.

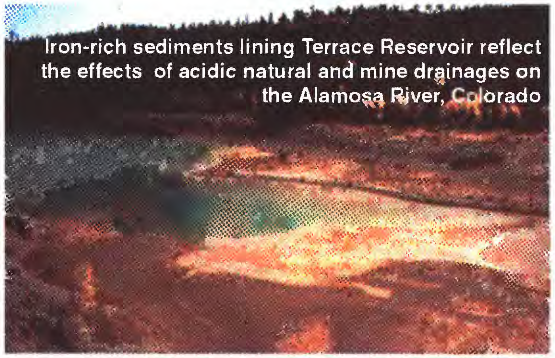
Reynolds Tunnel, Summitville

Underground and open-pit mine workings expose large amounts of sulfides to weathering in an oxygen-rich environment. The workings then channel the resulting acid- mine drainage out into the environment.

Solid Mine Wastes

Solid waste material such as mine waste dumps and mill tailings can be major sources for acid waters and metals in the environment.

Mill Tailings, Bonanza

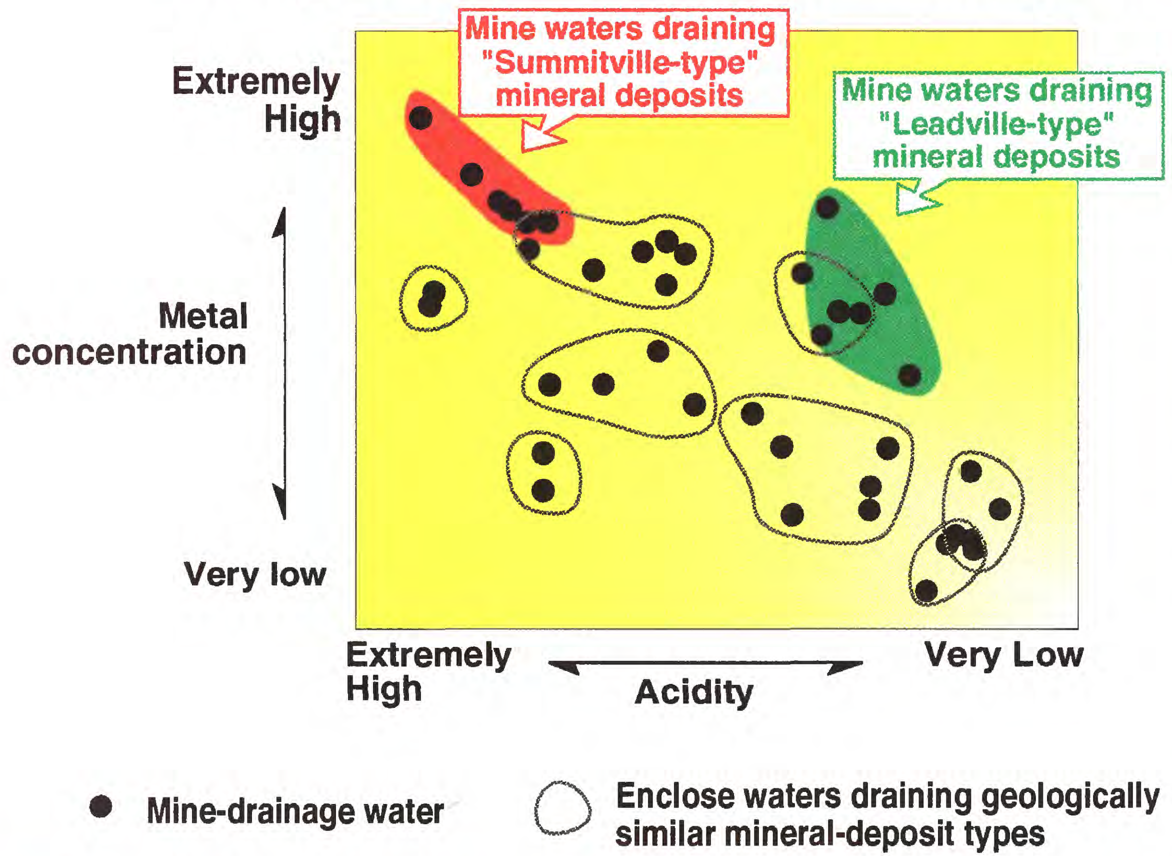


Iron-rich sediments lining Terrace Reservoir reflect the effects of acidic natural and mine drainages on the Alamosa River, Colorado

The Result

Acid waters and toxic metals can adversely affect water quality, aquatic life, wildlife, and agriculture. These effects underscore the need for more effective methods for predicting and remediating the environmental effects of mineral development.

Predicting the Chemistry of Colorado Mine Drainages Using Environmental-Geology Models



This graph demonstrates the control of mineral-deposit type on metal contents and acidities of mine-drainage waters in Colorado. Mine waters with higher acidities drain deposits with greater pyrite contents and lower carbonate contents. Waters with higher metal concentrations drain mineral deposits with greater pyrite and sulfid contents. Data collected and interpreted by W. Ficklin, K. Smith, G. Plumlee.

Environmental-Geology Models of Mineral Deposits

USGS/OMR research shows that different mineral-deposit types have characteristic environmental signatures (such as mine-drainage chemistry) that are a predictable function of mineral-deposit geology, geochemical processes, climate, and mining method.

The USGS/OMR is currently developing general environmental-geology models for various mineral-deposit types.

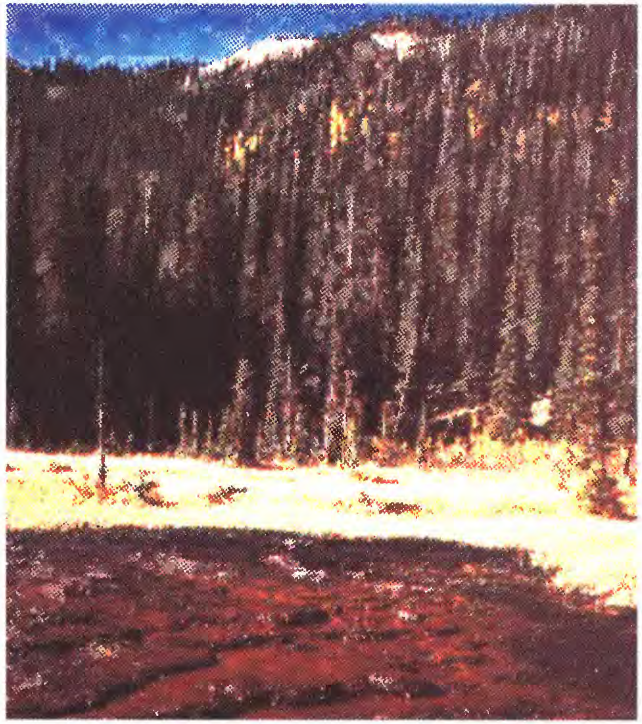
These models define, for different mineral-deposit types, the likely environmental signatures that existed prior to mining and that result from mining.

U.S. Department of the Interior
U.S. Geological Survey

Center for Environmental Geochemistry and Geophysics
CEGG

Integrated Mineral-Resource and
Mineral-Environmental Assessments
of Public Lands:
Applications for Land Management and Resource Planning

II. Mineral Resource-and Mineral-Environmental Assessment of Colorado for Selected Mineral-Deposit Types



Iron terraces (foreground) precipitating from a natural acid spring, Alamosa River, Colorado

Colorado Streams Affected by Metals

Figure Modified From Colorado Water Quality Control Division, 1989 Colorado Nonpoint Assessment Report.

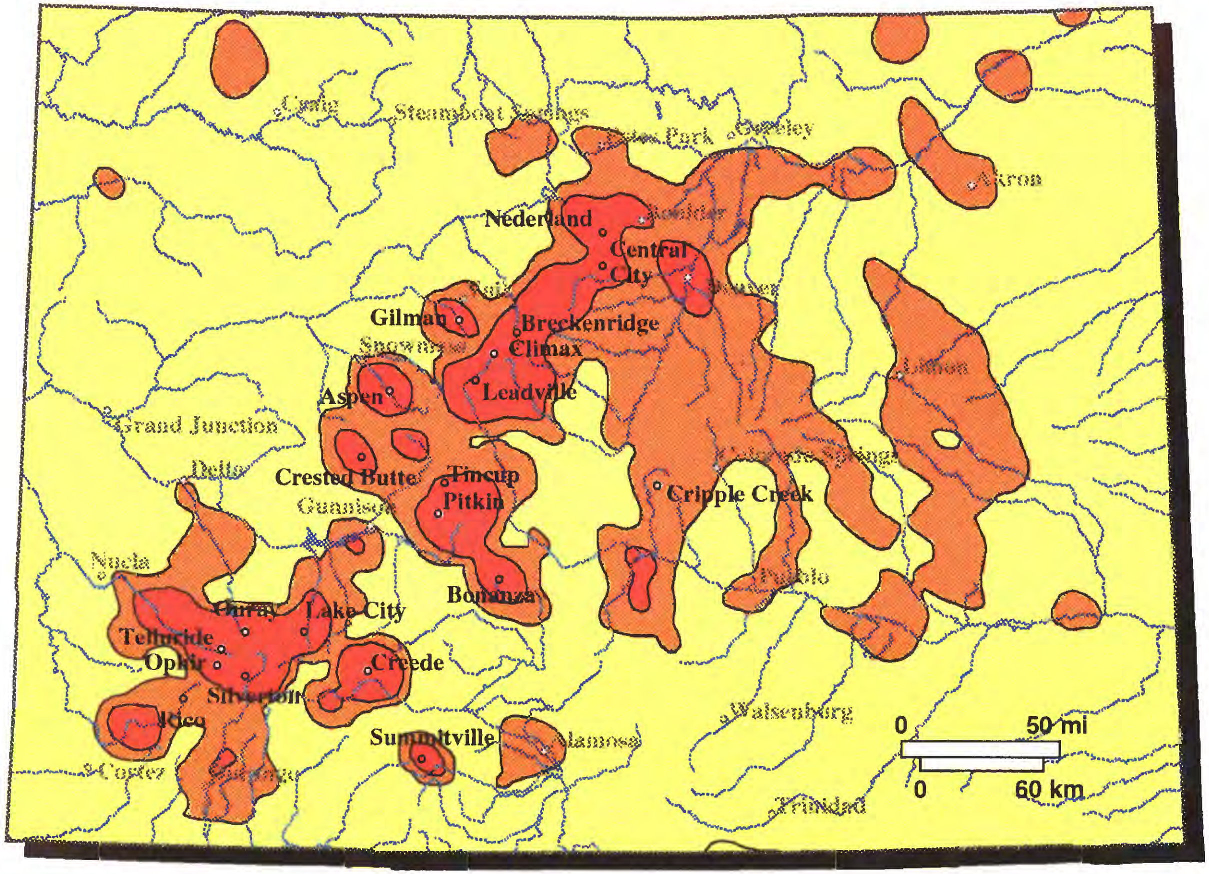
The Colorado Water Quality Control Division has determined that over 1300 miles of rivers and streams in Colorado are affected by metals.

The origin of metals in most affected Colorado streams can be traced to waters draining mines, mine waste dumps, mine tailings, or smelter sites.

In addition, a number of unmined areas are natural sources for metal contamination.

USGS/OMR mineral-environmental investigations provide insights into the processes that control the availability, mobility, and fate of metals in the environment.

Lead in Stream Sediments of Colorado



Lead concentrations greater than crustal average

Lead concentrations 4 times greater than crustal average

Lake City Mining District

Alamosa Major city or town

Data source: National Uranium Resource Evaluation (NURE) data contained within the USGS National Geochemical Database. Compiled by S. Smith.

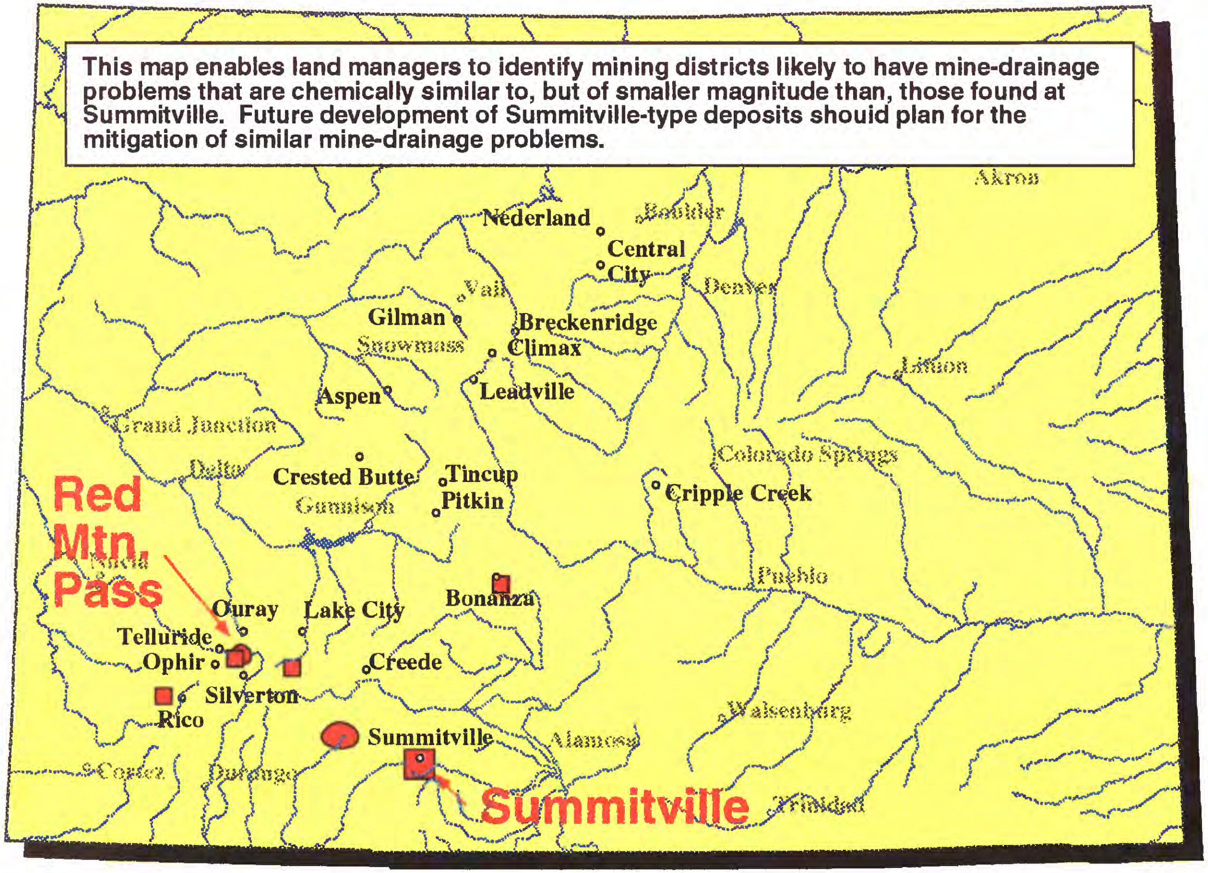
USGS Regional Environmental Geoscience Studies

USGS regional geochemistry and geophysics surveys map the distribution of metals and other potentially hazardous materials. These surveys also help locate sources of natural and human-induced environmental contamination.

A regional geochemistry study in Colorado shows that the greatest lead concentrations in stream sediments occur around mining districts. Lead also comes from unmined mineralized areas.

In metropolitan areas, lead sources include automobile, smelter, and industrial emissions.

"Summitville-Type" Mineral Deposit Occurrences in Colorado



- Major mine or district
- Smaller mine, district, or prospect
- Area of potential mineral-deposit occurrence

Lake City — Mining District

Alamosa — Major city or town

Environmental-Geology Model of "Summitville-Type" Deposits

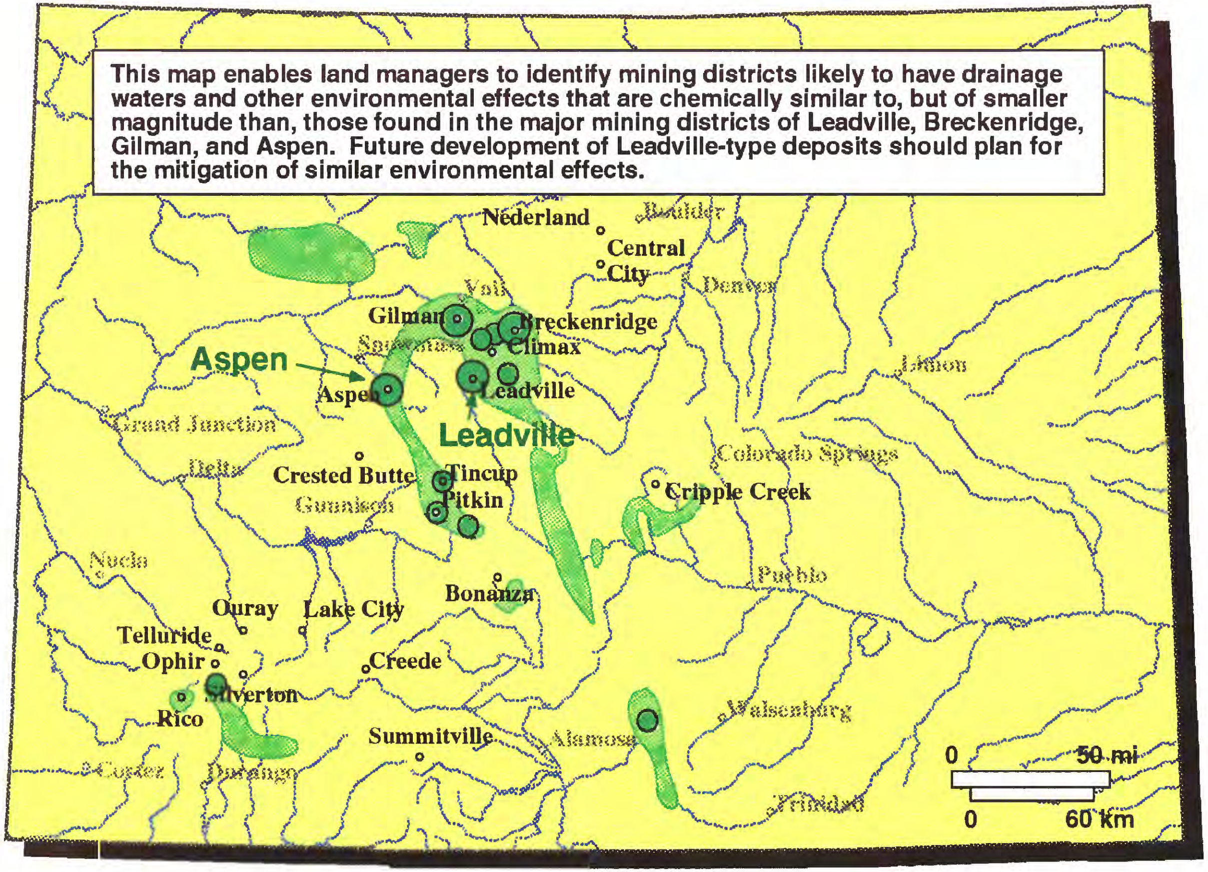
Geologic characteristics:

- wallrock is intensely altered to silica, alunite, kaolinite, and clays
- acid-generating ore minerals are abundant, including pyrite and copper- and arsenic-bearing sulfides.
- few minerals are present that react with and consume acid generated by sulfide weathering

Drainage-water characteristics:

- highly acidic waters with extreme concentrations of copper, zinc, arsenic, cobalt, uranium, thorium and many other metals.

"Leadville-Type" Mineral Deposit Occurrences in Colorado



Major mine or district

Smaller mine, district, or prospect

Area of potential deposit occurrence

Mineral deposit types and terranes compiled by S. Ludington, A. Wallace, T. Nash, B. Berger, B. Moring.

Lake City Mining District

Alamosa Major city or town

Environmental Geology Model of "Leadville-Type" Deposits

Geologic characteristics:

- Ore consists of massive sphalerite, galena, and acid-generating pyrite
- Ore occurs in veins and as replacements of carbonate-rich sedimentary rocks such as limestones.
- Some vein ores occur in igneous intrusive rocks that lack carbonates.

Drainage water characteristics:

- Mine waters in most carbonate-hosted ores generally have high concentrations of zinc but very low acidity.
- Waters draining some mine dumps and mines lacking carbonate minerals may be acidic with high concentrations of zinc, cadmium, lead, and arsenic.

Applications of Regional Geoscience Surveys and Environmental-Geology Models to Land Management and Resource Planning

U.S. Department of the Interior · U.S. Geological Survey

Center for Environmental Geochemistry and Geophysics (CEGG)

REGIONAL GEOSCIENCE SURVEYS:

- Map and identify sources of metal contamination.
- Are a cost-effective screening technique to help identify watersheds at risk for metal contamination.

ENVIRONMENTAL-GEOLOGY MODELS OF MINERAL DEPOSITS:

- Use geologic characteristics to predict likely environmental signatures of different mineral deposit types. The signatures include, for example, the types, concentrations, and mobilities of metals and other chemical elements.
- Allow mineralized areas and existing mining districts to be classified according to their likely environmental hazards.
- Enable industry, regulators, and land-use planners to more effectively predict and plan for the environmental effects that would result from the development of identified and postulated mineral resource occurrences on public lands.

White aluminum-rich sediments precipitating from mine-drainage waters—Ophir Pass, Colorado

U.S. Department of the Interior
U.S. Geological Survey

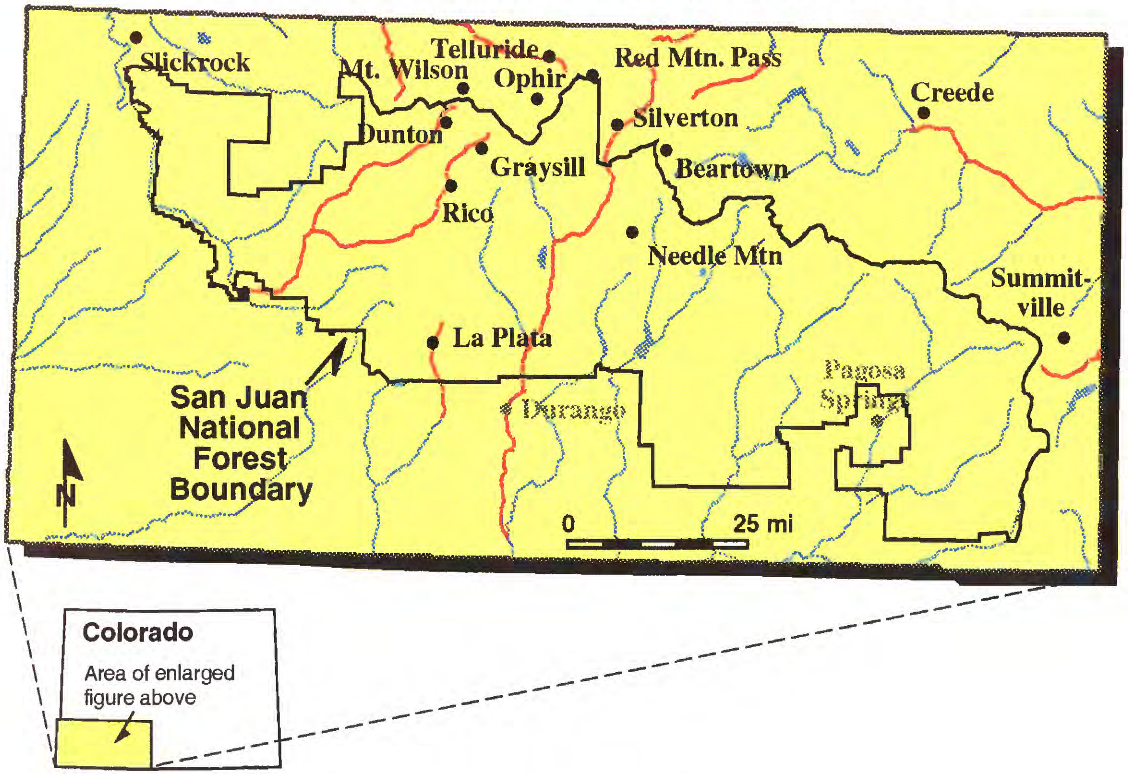
Center for Environmental Geochemistry and Geophysics
CEGG

Integrated Mineral-Resource and
Mineral-Environmental Assessments
of Public Lands:
Applications for Land Management and Resource Planning

III. Mineral-Resource and Mineral-Environmental Assessment of the San Juan National Forest, Colorado

Iron-rich sediments lining Terrace Reservoir reflect the effects of acidic natural and mine drainages on the Alamosa River, Colorado

Streams Affected by Metals
San Juan National Forest, SW Colorado



Telluride● **Mining District**

Durango **Major Town or City**

Stream affected by metals

Modified from Colorado 1989
Non-Point Assessment Report.

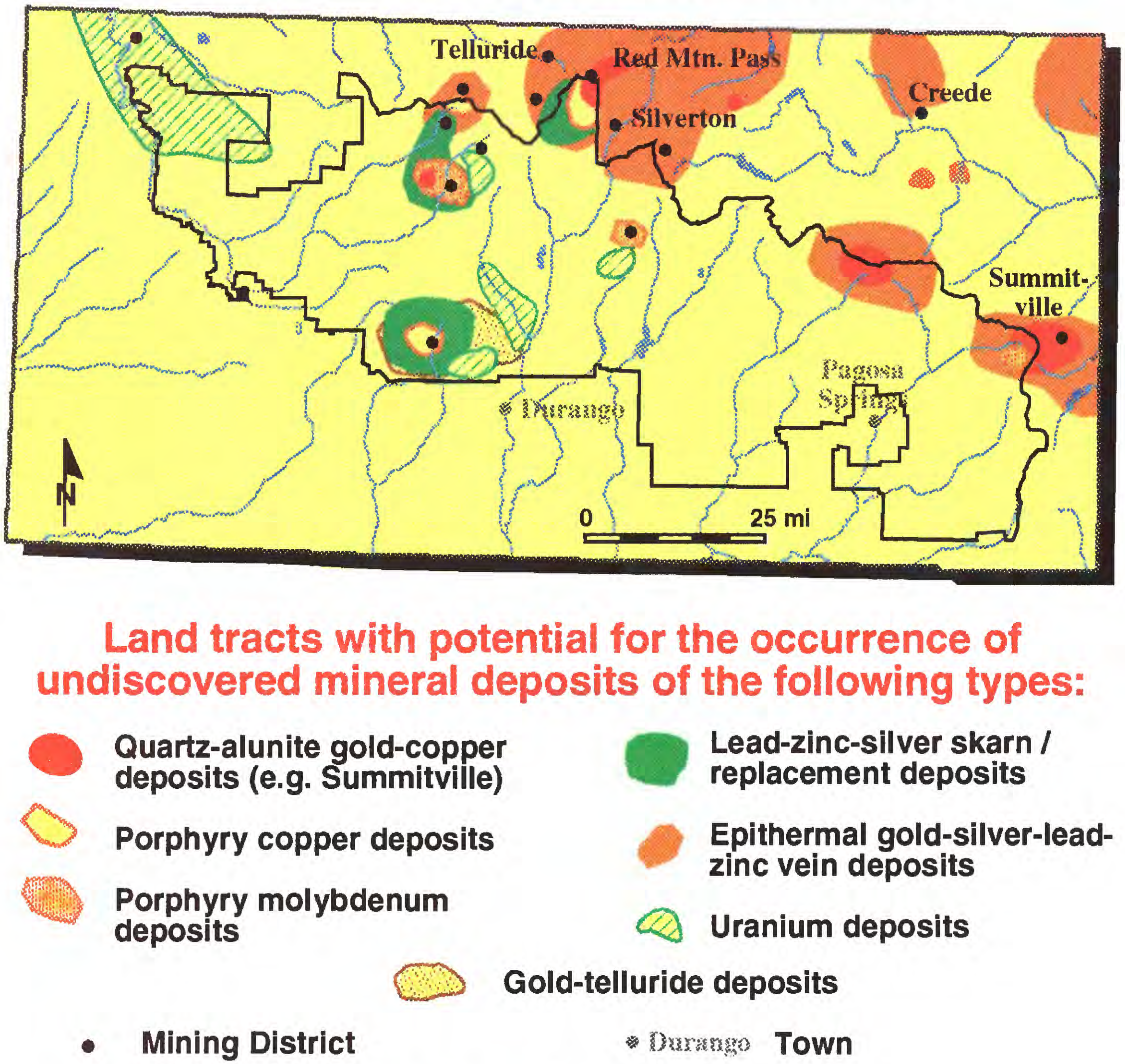
Prototype Mineral-Resource and Mineral- Environmental Assessment, San Juan National Forest

USGS/OMR is completing a Mineral Resource Assessment of the San Juan National Forest, SW Colorado.

Streams draining both existing mines and unmined mineralized areas have contributed to degraded water quality in many streams and rivers (shown in red).

Example products of an integrated environmental assessment of the Forest are shown in the next several pages.

Mineral-Resource Assessment Map
San Juan National Forest, SW Colorado



Compiled by T. Nash, R. VanLoenen, N. Foley.

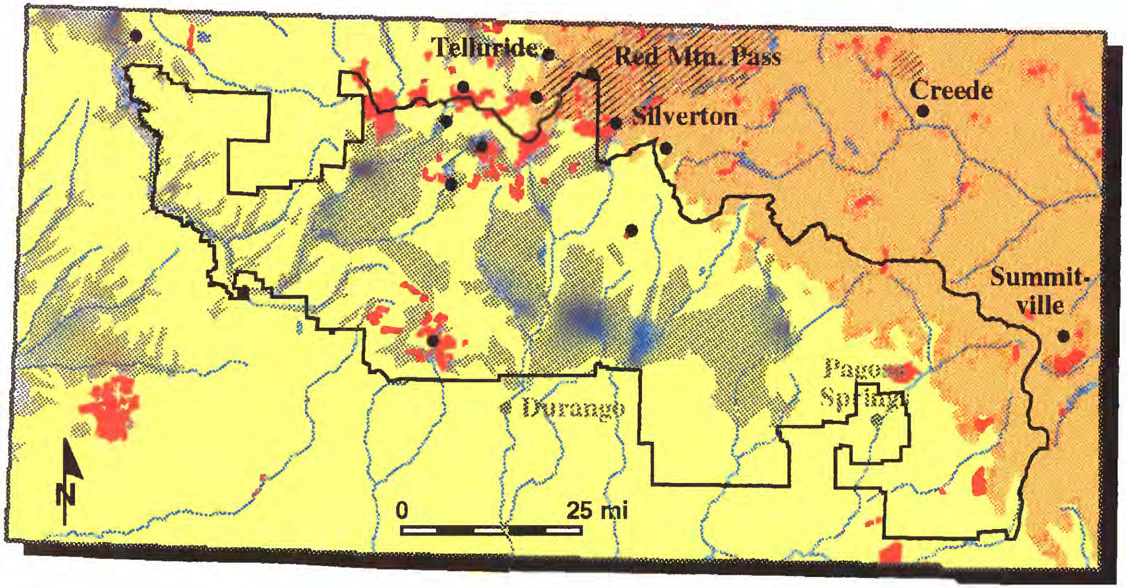
Mineral-Resource Potential, San Juan National Forest

This map identifies tracts of land that are geologically favorable for the occurrence of various undiscovered mineral-deposit types.

The tracts provide an indication of the location and nature of potential future mining activity that might occur within the National Forest.

Geologic information compiled in the mineral-resource assessment is then coupled with environmental-geology models of mineral deposit types to develop the mineral-environmental assessment.

Environmental Geology Map
San Juan National Forest, SW Colorado



Very Effective Acid Neutralizers:

Rocks mineralogically altered and enriched in carbonates by mineralizing processes

Carbonate-rich sedimentary rocks

Ineffective Acid Neutralizers:

Volcanic rocks

Other carbonate-poor rocks

Potential Acid Generators:

Intrusive rocks

● Mining District

Durango Major Town or City

Geologic map units compiled by G. Green.

The Influence of Geology on Stream- and Ground-Water Chemistry

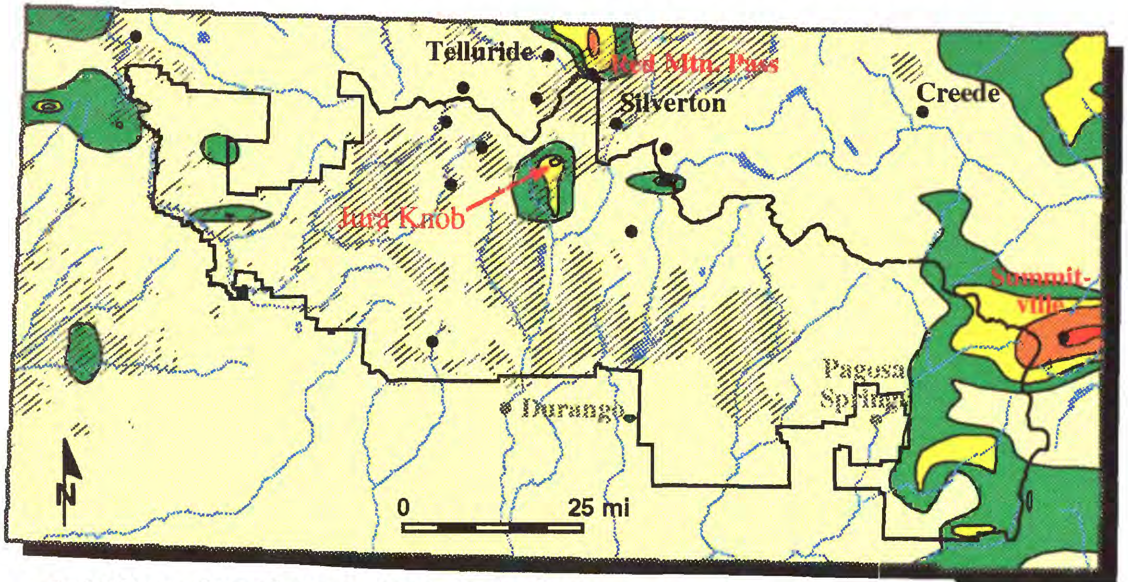
Different rock types can strongly affect the chemistry of waters that flow through or over them.

Rock units that contain abundant carbonate minerals:
- neutralize acid waters
- help mitigate acid-mine drainage naturally

Intrusive rocks:
- often contain abundant pyrite (iron sulfide) that can generate naturally acidic and metal-bearing waters

Acidity of Surface Waters

San Juan National Forest, SW Colorado



Acidities of surface waters, including major streams shown in blue, are denoted by the following map colors:

Increasing acidity ↑

- Acidic
- Near-neutral
- Near-neutral to alkaline

Carbonate-rich rocks

• Mining district

Durango — Major Town or City

Data source: National Uranium Resource Evaluation (NURE) data, collected 1976, USGS National Geochemical Database.

U.S. Department of the Interior — U.S. Geological Survey

Center for Environmental Geochemistry and Geophysics — CEGG

Influence of Mining and Rock Types on Stream Acidity

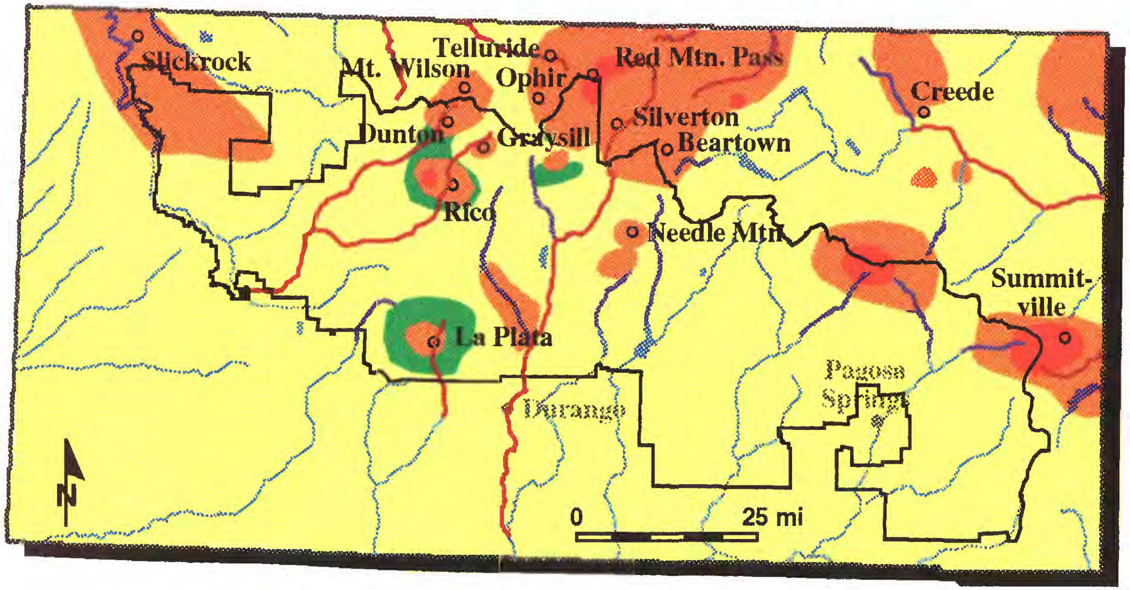
The downstream influence of mine-drainage on stream acidity is most extensive for mineral-deposit types that:

- generate the most acidic drainage waters and/or
- occur within carbonate-poor host rocks

Examples include the Summitville and Red Mountain Pass deposits.

Pyrite-bearing intrusive rocks, such as at Jura Knob, are common natural sources of acidity.

Mine Drainage Risk Assessment
San Juan National Forest, SW Colorado



Areas affected by, or potentially at risk from:

- Highly acidic waters with extreme metal concentrations
- Acidic waters with high metal concentrations
- Near-neutral waters with high metal concentrations

● Mining District

Durango Major Town or City

Major stream with known metal contamination:

Major stream with potential for present or future metal contamination:

Assessment based on mineral-resource tracts compiled by T. Nash, R. Van Loenen, N. Foley

Geology-based Environmental Risk Assessments of Public Lands

Environmental-geology models of mineral deposits are used in conjunction with mineral resource tracts to establish risk for environmental hazards on public lands.

The risk assessments are used to:

- Help identify and prioritize the study of existing hazardous mine sites
- Help predict and plan for the environmental effects of future mineral development

Applications of Integrated Mineral-Resource and Mineral-Environmental Assessments to Land Management and Resource Planning

GEOLOGY-BASED ENVIRONMENTAL RISK ASSESSMENTS:

- Show the types of geologic information needed by industry, regulators, and land-use managers to better assess the environmental effects of past, present, and future mineral-resource development.

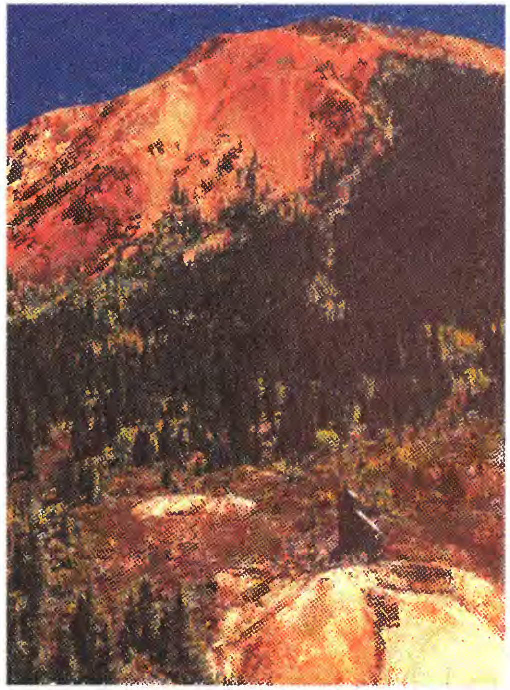
- Identify the types and extent of environmental effects from mining districts and unmined mineralized areas.

- Enable land managers to better identify and prioritize the study of environmentally hazardous mine sites within public lands.

- Enable better prediction of and planning for the likely environmental consequences resulting from the development of mineral-deposit types within a land unit.

For example, environmentally risky mineral-deposit types (such as Summitville-type deposits) should require extensive planning and engineering prior to development in order to minimize environmental effects on surrounding lands.

However, these deposit types could be developed with lower environmental costs if they occur in environmentally favorable geologic units (such as those containing abundant carbonates).



Acidic and metal-bearing waters drain sulfide-rich mines, mine dumps, and unmined mineralized rocks—Red Mountain Pass, Colorado